On the Electrification Produced during the Raising of a Cloud of Dust.

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In a paper published in the 'Philosophical Magazine' of May, 1913, an account is given of some experiments which show that the raising of a cloud of dust is accompanied by the production of a large amount of electricity. The dust was usually blown away from the surface of a flat piece of material or from the end of a tube. Large quantities of electricity were produced by this means and the sign of the charge seemed to depend upon the nature of the material used to form the dust cloud. Basic bodies generally acquired a negative charge, and acidic bodies a positive charge. It might be suggested that the origin of the charges lay in the friction of the particles of material against the surface from which they were blown, but this, however, is not altogether the case, as the following experiment will show.

An insulated brass tube, 25 cm. in length and 1·5 cm. in diameter, was connected to an electroscope. Tubes of different materials and of a slightly smaller diameter were provided to fit inside it so that the nature of the surface from which the dust was blown could be varied. Under these circumstances it might be expected that the charge carried away by the dust, and also that retained by the tube, would vary with the nature of the surface, but this was not the case, for with the same substance for creating the dust, the electrification was always the same no matter what was the nature of the surface from which it was blown. For example, sand always furnished a positive charge and red lead a negative one, and other materials gave charges of the signs given in the paper referred to. Again, the nature of the surface against which the dust was projected was also without influence upon the charge acquired. Clouds of dust were raised by blowing a current of air through the dust contained in a small wash-bottle, and the cloud projected against an insulated plate connected to an electroscope. The charge gained by the plate was of the same sign whether the plate was rough or smooth, or coated with different materials, so that it appears evident that the charge is actually produced upon the dust cloud itself. It has been shown that the charge upon the dust is apparently* accompanied by one of opposite sign upon the air, and a convenient arrangement for showing the presence of these two charges is given in fig. 1. The dust raised by blowing air through W is projected against the wire gauze screen G and the greater portion is caught, but the air accompanying the dust is carried on. At some distance (50–100 cm.) behind the gauze a small radium-coated plate R served to collect any charge present upon the air. Electroscopes E_2 and E_1 indicate the charges acquired by G and R. A few typical cases are given in Table I.

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* See note, p. 263.

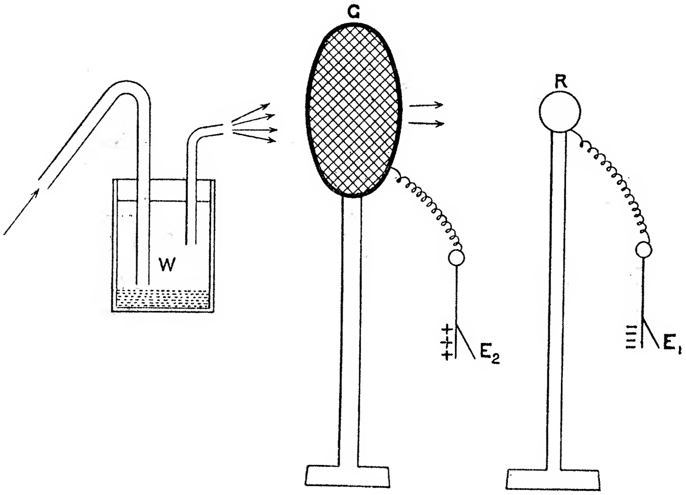

Fig. 1.

Table I.

Dust.	Charge upon gauze.	Charge upon air.
Red lead	−	+
Sand	+	−
Flour	−	+
Mercuric sulphide	+	−
Arsenious oxide	+	−
Zinc dust	−	+
Iron filings	−	+
Chalk	−	+

The electrification indicated by E_1 is not due to the friction of the dust against the wire gauze, for a charge of the same kind is shown by spraying the dust directly into the air.

Up to this point the work had been carried on at the University College, Bloemfontein, and in the open air, but since then the experiments as detailed in the original paper have been repeated under different climatic conditions, and also within a room in the Cavendish Laboratory. The result has been to confirm the previous experiments, and although some variations do occur, the general laws appear to be well substantiated.

In the earlier experiments there was a more or less free motion of air and dust permitted, but it was thought advisable to conduct the experiment in a confined space. For this purpose a wooden box 45 × 45 × 55 cm. was lined with tinfoil, and dust clouds raised in this by spraying through a hole in the side. Insulated conductors could be arranged inside, either to take the charge upon the dust, or upon the air. Wires connected to the electroscopes were passed through thick ebonite plugs into the box, one wire being attached to an insulated cylinder V just close to the hole through which the dust was projected, and the other to a small radium-coated plate R which was not in the direct path of the dust from the hole, fig. 2. With this

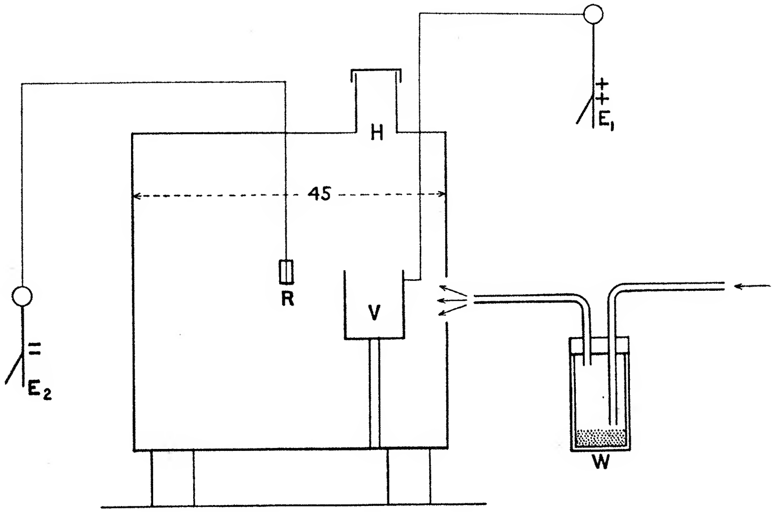

Fig. 2.

Table II.—Showing Charges on Air and Dust.

Substance.	Charge on air.	Charge on dust.
Red lead	+	—
Mercury sulphide	—	+
Silica	—	+
Chalk	+	—
Zinc	+	—
Sulphur	—	+
Flour	+	—
Morphine	+	—
Amygdalin	—	+
Quinine	+	—
Quinine sulphate	—	+

apparatus a number of experiments were made which showed practically the same results as those obtained by spraying in the open air. If the material used was silica, the charge upon the insulated vessel was positive and the charge upon the air negative, as would have been the case in the open air. If red lead was used, the charges upon conductor and air were negative and positive respectively.

This arrangement was very sensitive as a means of detecting the charge upon the air, and some attempts were made to get quantitative results, that is to find some relation between the charge of electricity upon the air and the quantity of material sprayed. Mercury sulphide was the substance used, as this was found to be the most efficient dust for producing electrification, but the efficiency depended upon the fineness of the powder. The finely powdered material was contained in a small wash-bottle, and the dust cloud raised by blowing air from a small rubber spraying bellows through it. It was found that fairly constant amounts of dust were carried away in each puff of air from the rubber spraying ball, but the amount was so small that it was practically unweighable, and the weight of the material associated with one puff had to be found as a mean from a considerable number of puffs. In this case a Dolezalek electrometer was used instead of an electroscope, as of course it was more sensitive. On sending the dust cloud into the box it was found that one puff was sufficient to charge the radium collector up to a potential of from 6 to 8 volts.

In order to find the average weight of material the wash-bottle was weighed carefully and then a definite number of puffs made and the bottle weighed again. If the material had been well sifted before being put in the bottle this gave very concordant results, as the table shows.

Table III.—Weight of Bottle and Contents.

		Loss in weight for 10 puffs.
Before puffing ……	78·177 grm.	
After 10 puffs ……	78·172	0·005 grm.
„ 20 „ ……	78·1673	0·0047
„ 30 „ ……	78·1625	0·0048
„ 40 „ ……	78·158	0·0045
„ 50 „ ……	78·1536	0·0044
„ 70 „ ……	78·144	0·0096 (20 puffs)

Loss for 70 puffs…………… 0·033 grm.
„ 1 puff …………… 0·00047 „

The mean of six series of similar determinations gave an average of 0·00053 grm. of HgS per puff.

Practically the whole of the volume of the air inside the box was charged, and assuming for a moment that the material was uniformly distributed throughout the volume of the air the amount of dust per cubic centimetre would be

$$\frac{0{\cdot}00053}{45 \times 45 \times 55} = 5 \times 10^{-9} \text{ grm. per c.c. approximately for one puff.}$$

Other material gave similar results, but nothing so far tested approaches mercury sulphide in the small amount required to produce a given charge. Molybdic acid was also very efficient. This small amount of dust, 5×10^{-9} grm. per cubic centimetre, gave a charge which raises the potential of the exploring electrode to several volts, so that the actual amount of dust which would produce a detectable charge might well be 1/1000 of this amount.

Blowing a few centigrammes of cornflour into a large room* charged the air to such an extent that a radium-coated collector rapidly indicated a potential of 200 volts, and the charge persisted for some time.

It is thus easy to understand how the very high potential gradient—over 10,000 volts per metre—may arise during a dust storm, and the lightning flashes which are stated to accompany eruptions of fine ashes from volcanoes may perhaps be referred to the same cause.

On several occasions it had been noted that a reversed charge was given to the wire gauze used to collect the dust, and this appeared to be due to the rate at which the cloud of dust was raised, as well as to the influence of the opposite charge upon the air. The box used for the last series of experiments was employed to carry out another series in which the dust was "rained" into the box instead of being sprayed. A hole, H, was bored in the top of the box and immediately below this a hollow insulated copper vessel connected to a Dolezalek electrometer was arranged. A radium collector could also be inserted when desired (fig. 2). The dust was sifted through fine lawn and in this case the curious result was obtained of a negative charge being nearly always given up to the insulated vessel, and the air as tested by a radium-coated conductor was also negative. Only very small amounts of material passed through the close meshes of the sieve; a milligramme or so of most substances would raise the potential of the insulated conductor to 3 or 4 volts. Varying the distance of fall from 10 to 30 cm. had no influence on the nature of the charge, but merely dropping the powder in a mass produced no charge, it being necessary apparently for the particles to be spread apart or rubbed together if a charge was to be obtained. For example, some reduced iron was dropped down a glass tube 40 cm. in length into the insulated vessel, and practically no charge was generated, but on tying a piece of fine lawn over the end of the tube and tapping, it gave a charge which sent the spot of light off the scale. Table IV gives some of the results.

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* The room had a volume of about 250 cubic metres.

Table IV.

Material.	Charge, raining.	Charge, spraying.
Silica	Negative	Positive.
Mercury sulphide	"	"
Red lead	Very slight negative, sometimes +	Negative.
Precipitated sulphur	Negative, but not strong	Positive.
Iron filings	" "	Negative.
Chalk	Very slight, but tending to −	"
Zinc dust	Negative*	"
Morphine	"	"
Cornflour	"	Positive.
Ground crystallised sulphur	"	"

* Varied with height of fall, above 20 cm. sometimes positive.

The experiments described so far had been carried out with air, and it seemed of interest to repeat them with the gases which can be obtained in cylinders, the pressure under which these gases escape furnishing a convenient method of raising the dust. The gases available were oxygen, hydrogen, carbonic acid, sulphur dioxide, nitrogen, and ammonia. Using the wash-bottle arrangement for raising the dust, a series of puffs of gas was sent through the bottle and the dust raised tested in the usual manner. Generally the same charges as with air were obtained.

A considerable amount of time was expended in endeavouring to measure the current which could be sent through air when dust was present, but the results were very unsatisfactory on account of the large charges initially present upon the dust. If ions are present, they most probably are of a large size, and hence would have a small velocity in a field of moderate strength, and under any circumstances a certain number of charged dust particles would reach conductors connected to the electrometer, but the current through the dust-laden air was very small. The general trend of the experiments seems to indicate that the air does become slightly ionised but not to an extent comparable with that produced by a trace of a radium preparation.

Up to the present no satisfactory explanation as to the origin of the charges had presented itself save the one that these charges might be due in some way to the enormous increase of surface of contact between the air and the dust which must occur when a small amount of powder is blown into a dust-cloud, somewhat in the same manner as a strong charge is produced by breaking up a liquid into a fine spray as shown by Lénard and others, and some experiments were made to test whether this was the case.

A brass tube, A, 30 cm. in length and 1·5 cm. in diameter, was provided with a wire gauze cap at G and projected into a copper vessel, B. At the end, P, paper tubes coated with mercury sulphide or other material could be inserted and a strong current of air or other gas directed over it from the nozzle, the air escaping at the wire gauze end. The two electroscopes would indicate any charge acquired by the paper or carried away by the current of air, fig. 3. At first small charges were indicated by both electroscopes, that on the one attached to the tube being positive whilst that on the copper vessel was negative, as would be expected to be the case with mercury sulphide, but the charges were only obtained for a short time, and were clearly due to some of the material being torn off mechanically. This was confirmed by rubbing the paper after the charges had ceased, and then the detached particles gave rise to charges on blowing. The same thing occurred if hydrogen was used instead of air. The air does not carry away a charge as a consequence of being blown over a surface of mercury sulphide or other material.

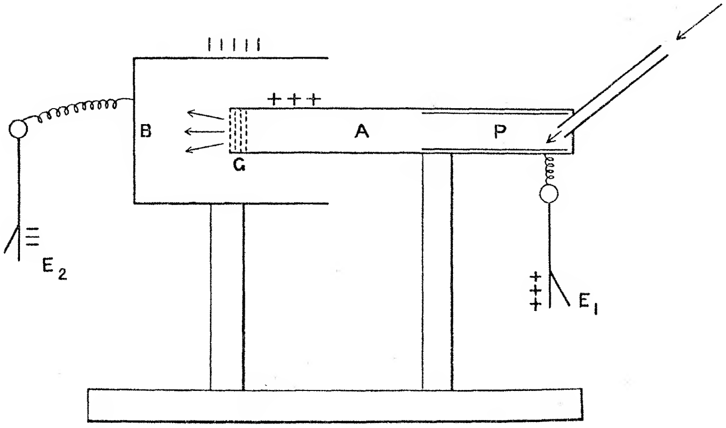

Fig. 3.

When a tube was packed with powder and the ends closed with plugs of cotton wool no charge was carried away by the air driven through the apparatus unless some powder managed to escape through the plugs. If the charge had been due to an effect of contact of air and dust some charge should have been obtained by this method. It must therefore be concluded that the charges are not due to mere increase of surface of contact between the air and the dust.

It was always easier to detect the charge upon the air* than upon the dust, and some determinations of the amount of electricity carried by the air and finer dust particles were made by observing the potential to which a conductor of known capacity was raised by it. The large tin-lined box used in the previous experiments was employed as a means of catching the charge upon the air. It was supported by three blocks of paraffin and a wire from the metal lining joined to an electroscope. The capacity of the arrangement was about 70 cm.

On blowing in some mercury sulphide from the bottle the box became strongly charged with negative electricity, and after two puffs of air the whole apparatus was charged up to a potential of 50–60 volts. The quantity of electricity carried by the air and dust into the chamber under these circumstances was about 12 E.S. units, and the charge per cubic centimetre about

$$\frac{12}{45 \times 45 \times 55} = \frac{1}{10000} \text{ unit.}$$

Instead of the tube from the bottle being allowed to project directly into the box an earth-connected metal tube was sometimes inserted between the two. This, however, had but a small influence on the magnitude of the charge, which seems to be generated when the dust, so to speak, suddenly expands.

A very extreme case of this kind was seen when the dust on its way to the box was passed through 20 feet of compo piping, 0·4 cm. in diameter. Using cornflour for the dust a very strong charge was given to its apparatus when only a centigramme or so of the powder had been sprayed. In one instance the powder was sprayed through the 20 feet of tubing into the room, and when less than 4 cgrm. had been sprayed, the air of the room was charged to such an extent that the radium collector indicated a potential of 100 volts. In some experiments made in a large tin vessel which could be closed air-tight it was found that the total charge upon air and dust together was zero.

It is difficult to locate the origin of the very strong charges possessed by both dust and air, and it seemed at first as though the mere act of raising the dust, and of thus increasing the area of contact between dust and air, might be sufficient to account for the charges developed, as may be done in considering the origin of the charges developed upon water spray and air, when larger drops of water are broken up into smaller ones; but it does not appear that the increase of surface of a mass of finely divided material when blown into a cloud, nor the mere friction of air against dust, is sufficient to account for the charges found upon dust and air. There remains then to be considered the case of friction of the similar dust particles against each other. Although the particles are of the same material there might easily be sufficient surface differences to permit of two particles becoming oppositely charged by rubbing against each other, and in this case it might be expected that equal charges would be generated upon the two particles which had been in contact, so that the charge upon the dust as a whole should be zero. Certain experiments already referred to, however, gave indications that the charge associated with a given substance was not absolutely fixed, and the fact that the charge obtained upon a certain dust was generally independent of the nature of the gas in which it was raised, and also independent of the nature of the surface from which it was blown, led to investigations being made to ascertain whether two charges were not actually present in the dust itself.

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* Perhaps the charge is not upon the air itself, but upon very fine particles carried along with the air, and these may not settle readily.

In many futile attempts to measure a saturation current through the dust-laden air it was noticed that the dust collected upon the electrodes between which it was tried to send a current, and it was further seen that one electrode became much more thickly covered with dust than the other. A number of experiments have been made with various materials to investigate this point, and the results will now be detailed.

The apparatus (fig. 4) used for carrying out the experiment consisted of an inverted glass bell-jar having an opening at the bottom and covered on the top by a plate of thick zinc through which passed wires connected to two insulated cylindrical conductors. These conductors were connected to the terminals of a battery of 400 secondary cells, the central point being earthed, so that the conductors were equally and oppositely charged. Through the cork at the bottom the tube from the spraying bottle passed, and by sending in a gentle current of air through O, a mixture of air and dust passed through the apparatus, the excess escaping through X. In some cases X was closed and O connected to a bulb so that dust might be raised without any air leaving the apparatus. No particular advantage resulted from this, and the amount of dust collected upon the conductors was much smaller. In some cases a lining of earth-connected wire gauze was placed inside the bell-jar, and in fact a metal vessel is best, but it was of interest to watch the deposition of dust upon the electrodes. The electrodes were made of brass and highly polished, and were attached at the sides to the supporting rods so that by rotation they could be arranged at different distances from each other. Various voltages were applied to A and B without producing an essential difference save that of varying the rate of collecting the dust, which gathered on all parts of the electrodes, but if these were close together, collected in greatest amount on the portions of A and B facing each other.

If the electrodes were uncharged only a small amount of dust settled on them; the air escaping, however, was strongly charged, as was seen from the electroscope connected to the radium collector placed near X. The results of some typical cases are given in Table V (p. 266).

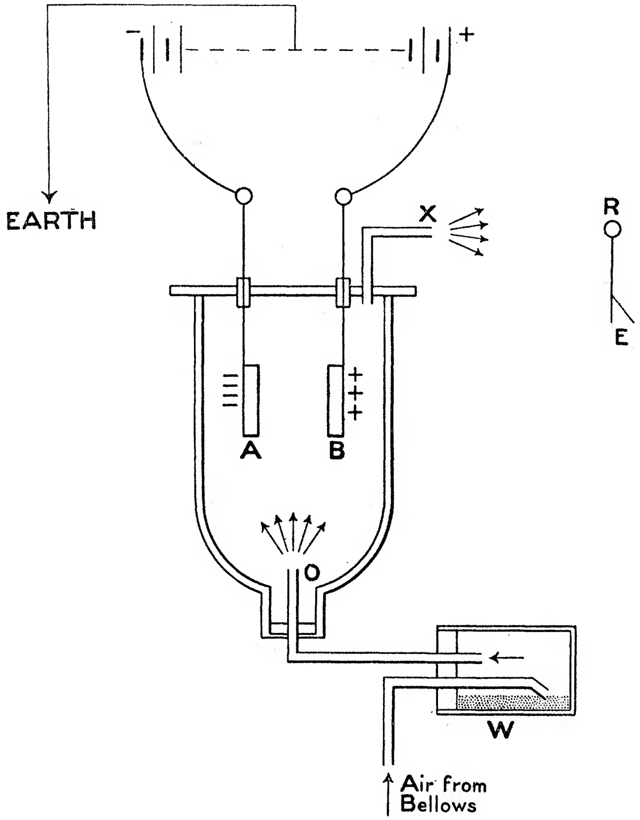

FIG. 4.

In most cases examined there was a very marked difference in the amount of dust collected upon the electrodes, and the greater this difference the greater the charge carried away by the air. The charge carried away by the air was always opposite to that upon the electrode which attracted the greater quantity of dust.

If one can measure the amount of charge from the mass of the dust attracted to the electrode, then, if the greater quantity goes to the positive electrode, *i.e.* has a negative charge, we might expect that the air should have

Table V.

Material used.	Charge upon the air.	Excess of dust upon—	Charge upon air.
Flour	+	− electrode	Great.
Fine silica	−	+	”
Mercuric sulphide	−	+	”
Red lead	+	−	”
Sulphur	−	+	”
Bismuth oxide	+	−	Small.
Chalk	+	−	”
Zinc dust	−	+	Great.
Iron filings	−	+	Variable.
Copper oxide	+	−	Slight.
Magnesium oxide	−	+	Uncertain.
Molybdic acid	−	+	Very great.
Mercuric oxide	+	−	Slight.
Antimony	−	+	
Arsenious oxide	−	+	Great.
Road dust	−	+	Variable.
Coal dust	+	−	”
Portland cement	+	−	Great.
Quinine	−	+	Small.

a positive charge, whereas the opposite is the actual case. It is true that all the dust is not collected by the electrodes and that a further electrification is produced when the excess of dust escapes into the air surrounding the apparatus.

As there was such a considerable difference in the appearance of the two electrodes after the deposition of the dust, it seemed possible that some quantitative relation might exist between the amount of dust attracted by the two electrodes, and a number of measurements were made of the actual quantity of dust deposited. If the electrodes were well polished and uncharged, the amount of dust deposited upon them in a reasonable time was practically unweighable, but if they were charged there was no difficulty in determining the weight of material upon both electrodes.

The method of making the determinations was as follows:—

The electrodes were well polished and weighed upon a balance to 0·1 mgrm., and after the deposition of the dust weighed again.

In Table VI (1) gives the weight of the electrode before the deposition of dust, and (2) the weight afterwards. In the last column the ratio of the greater to the smaller gain in weight is given, and this is positive/negative or negative/positive according to the nature of the dust. Many observations were made but only a few are included in the table, and these are typical.

The ratio of the masses of the charged powders is not very uniform save in the cases of mercuric sulphide and cornflour; there the value is somewhat of the order of 2 : 1, but in the opposite sense as regards the signs of the

Table VI.

Weight of + electrode.			Weight of − electrode.			Ratio
(1).	(2).	Gain.	(1).	(2).	Gain.	$\frac{\text{Gain}+}{\text{Gain}-}$.
			Mercuric Sulphide.			
25 ·9037	25 ·9051	0 ·0014	25 ·9072	25 ·9079	0 ·007	2 ·0
25 ·9037	25 ·9124	0 ·0087	25 ·9072	25 ·9114	0 ·0042	2 ·07
25 ·9037	25 ·9152	0 ·0115	25 ·9072	25 ·9127	0 ·0055	2 ·04
25 ·9040	25 ·9085	0 ·0045	25 ·9076	25 ·9096	0 ·002	2 ·25
			Cornflour.			
						$\frac{\text{Gain}-}{\text{Gain}+}$.
25 ·9025	25 ·9156	0 ·0131	25 ·9072	25 ·9351	0 ·0279	2 ·1
25 ·9025	25 ·9150	0 ·0125	25 ·9072	25 ·9333	0 ·0261	2 ·1
			Molybdic Acid.			
						$\frac{\text{Gain}+}{\text{Gain}-}$.
25 ·8905	25 ·9000	0 ·0095	25 ·9030	25 ·9042	0 ·0012	7 ·99
25 ·9040	25 ·9086	0 ·0046	25 ·9020	25 ·9051	0 ·0031	1 ·48
			Red Lead.			
						$\frac{\text{Gain}-}{\text{Gain}+}$.
25 ·3350	25 ·3380	0 ·003	25 ·3360	25 ·3485	0 ·0125	4 ·12
25 ·9032	25 ·9070	0 ·0038	25 ·9075	25 ·9320	0 ·0245	1 ·0
25 ·9032	25 ·9080	0 ·0048	25 ·9075	25 ·9217	0 ·0142	2 ·96

charges in the two cases. The difference in the masses was not due to a difference in the individual size of the charged particles, as far as could be determined by the microscope, but it may be that a group of particles clinging closely together might be struck by a number of smaller or individual particles, and thus acquire opposite charges, and in some cases it did seem as though the negatively charged particles shaken off the positively charged electrode were larger than the positively charged ones shaken off the negative.

An attempt was made to see whether any separation of the charged particles could be brought about by settling under gravitation, and with this object a box 120 cm. in length, 20 cm. in depth, and 20 cm. in breadth was taken and three pairs of insulated electrodes inserted in the cover. Holes at the two ends of the box allowed of a cloud being blown in at one end, and of the excess of dust escaping at the other. The electrodes were joined in parallel to the leading wires, and were charged by a battery of small cells to a difference of potential of about 800 volts. The respective pairs (1), (2), (3) of the electrodes were carefully weighed, a current of dust passed through the air for a short time and the electrodes again weighed. Some of the results obtained are given in Table VII:—

Table VII.—Long Box Experiment. Dust used, Cornflour.

First pair of electrodes.		Ratio −/+.	Second pair of electrodes.		Ratio −/+.	Third pair of electrodes.		Ratio −/+.
Gain in weight +.	Gain in weight −.		Gain in weight +.	Gain in weight −.		Gain in weight +.	Gain in weight −.	
(1) 0·026	0·0625	2·4	0·0078	0·043	5·5	0·0020	0·0079	4·0
(2) 0·0088	0·050	4·3	0·0076	0·032	4·2	0·0015	0·0145	9·7
(3) 0·0196	0·0615	3·14	0·0025	0·0268	10·7	0·002	0·017	8·5
(4) 0·0093	0·0312	3·3	0·0088	0·0454	5·0	0·0013	0·0060	4·6

In this table it is seen that the ratio of the masses of the positively charged particles to those of the negatively charged ones increases with the distance from the origin of the cloud; that is the positively charged particles travel a greater distance before settling. It may be that this is merely an accidental relation, or that the positively charged particles are finer and are carried farther. Of course, there are so many factors which could interfere that it is not safe to generalise.

From the experimental details which have been given, it seems quite clear that the electrification must be due to some mutual action amongst the dust particles, such as repeated contact or the rubbing of one particle upon another. Small charges only would be produced upon the individual particles, but, as there are so many, the collective effect might well be great. It is, of course, well known that, by rubbing together two pieces of the same material, two charges of electricity can be obtained, it being presumed that there exists naturally some slight difference between the two surfaces which are being rubbed, and no doubt many observations have been made upon the matter, but the cases recorded are few.

Some experiments were therefore made to ascertain to what extent naturally occurring ordinary bodies gave rise to measurable charges of electricity when rubbed together; it appears that practically every material is found to become charged when rubbed on another piece of the same material, the two pieces becoming oppositely charged.* The charges produced are comparatively large, so that no difficulty is experienced in detecting them with an ordinary electroscope, and very small pieces of material suffice to give measurable charges. The sign of the charge upon each piece of material is apparently fortuitous, for, given two pieces, A and B, of the same material, then A may be positive at one time and B at another; probably there is some slight surface difference, which is not permanent. Amongst the substances examined, and which readily gave the two charges when two pieces are rubbed together, are quartz, cinnabar, Iceland spar, arragonite, tourmaline, barytes, felspar, mica, fluor spar, sulphur, potassium nitrate, potassium bichromate, and oxalic acid. This list is representative, but not exhaustive, and in each case opposite charges are obtained from two pieces of the same substance. Of course, rubbing two pieces of dissimilar substance also gives rise to two charges.

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* Hesehus, 'Journ. de la Soc. Russe Phys.-Chim.,' 1901, states that when pieces of similar material are rubbed together they become charged with the *same* kind of electricity, and the dust abraded has a charge of opposite sign.

It is very surprising what small amounts of material will acquire measurable charges. Pieces of cinnabar not more than 0·1 sq. cm. in area give very definite charges.

In addition to the charges upon the materials, some charge is also given to the air surrounding the material, and the sign of this charge depends upon the nature of the material. Thus, by rubbing two rhombs of calcite together inside a box in which was present an insulated wire coated with radium and connected to an electrometer, the latter indicated that a positive charge had been gained by the wire, but if two crystals of quartz were used, then the charge was found to be negative. This agrees with the signs of the charges given to air during the raising of a dust cloud of these materials. These charges upon the air were not very strong, but quite definite, especially in the case of calcite, when the sign was always positive. It is most probable that small particles are abraded during the rubbing, and these may give a charge to the air, and it is possible that in all cases the charge upon the air is really due to very fine particles which do not readily settle, or which move with such velocity that they escape capture by the charged electrodes used in certain of the experiments.

Some examples of the electrification produced by rubbing crystals together are now given.

Quartz upon Quartz.

Large crystal.	Charge.	Small crystal.	Charge.
Pyramid face (1)...........	+	Pyramid face (1)...........	–
Prism „ (1)...........	+	Pyramid „ (1)...........	–
Prism „ (1)...........	+	Prism „ (1)...........	–
Pyramid „ (3)...........	+	Pyramid „ (2)...........	–
Prism „ (2)...........	+	Prism „ (3)...........	–

In this series the large crystal was always charged positively, but, on repeating the experiment later, the reverse was seen. The electrification is independent of the orientation of the crystal faces.

The large crystal was then used to rub other quartz crystals, and it generally acquired the same charge. With "smoky" quartz only a very feeble charge could be obtained.

In crystals of quartz there is a distinct difference in the nature of the surface of the prism and the pyramid faces, and it might have been expected that some difference in the charges would have been noted, but this was not the case. Iceland spar is, however, a simpler crystal, and one which has fewer faces, and the six faces are mineralogically the same. A large crystal of Iceland spar was broken into pieces and two fair-sized rhombs selected for experiment. These were rubbed on each other in a definite order so as to bring the different faces successively into use. A number of experiments was made with each face, allowing a short interval between each rubbing. One crystal generally remained positive with reference to the other, quite independently of the particular faces used, but occasionally a reversal occurred, and, by allowing the crystals to rest for some time, the one formerly positive might now be negative. As with quartz, the charge upon the crystal was independent of the orientation.

A crystal of arragonite was rubbed on one of calcite, varying the faces used. In every case the arragonite was positive to calcite.

A few cases of mixed crystal are now given :—

Arragonite	+	Calcite	–
Fluor spar	+	Calcite	–
Tourmaline	+	Calcite	–
Barytes	+	Calcite	–
Quartz	+	Calcite	–
Barytes	–	Quartz	+
Felspar	–	Quartz	+
Felspar	+	Calcite	–

A couple of "worked" quartz plates were found to be most efficient. The temperature of the plates was varied and the electrification observed, and the sign of the electrification is apparently not affected by the initial temperature of the two plates, which would soon be equalised by contact.

Plate A.		Plate B.	
Cold	+	Cold	–
Hot	–	Cold	+
Cold	–	Cold	+
Hot	–	Cold	+
Cold	+	Cold	–
Cold	–	Hot	+

Plate A.		Plate B.	
Hot	+	Hot	−
Cold	+	Hot	−
Hot	−	Hot	+
Hot	−	Hot	+
Cold	−	Hot	+
Hot	+	Cold	−

In general, naturally occurring crystals of material are the most suitable to employ, because the surfaces are fairly definite in condition, and also because they are better insulators than pieces of amorphous material. The sign of the electrification acquired appears to be quite fortuitous.

The facts as revealed by the experiments are very difficult to interpret. At present it seems quite definite that the charges originate in the powder itself; that is, there must be friction or contact between the various particles, which differ in size or surface condition, in such manner, that two groups of oppositely charged particles are yielded by the dust from chemically homogeneous materials, and also that the air or gas used to raise the cloud either becomes itself electrified, or else carries with it very fine charged particles of the material. The total electrification of the two sets of charged particles and the air accompanying them is zero. The nature of the gas used to raise the cloud does not seem to be of much importance.

It was suggested to the writer that it might be possible to obtain some evidence of the presence of double layers surrounding the particles of dust, and to attempt their removal, but the experimental difficulties seem at present to be insurmountable. Some work was done in this direction by heating precipitated silica for some time in an exhausted tube, and then after cooling raising a cloud by shaking. Charges were, of course, obtained, but it was not possible to distinguish between those due to the agitation of the dust particles amongst each other, and those due to friction of the dust against the walls of the containing vessel.

Summary.

(1) The results of these experiments confirm generally those given in the former paper.

(2) The raising of a cloud of dust is accompanied by the production of large charges of electricity. Some of the dust particles have positive charges, and others negative.

Either one set of charged particles settles rapidly, leaving the other set in the air, or else a charge is given to the air itself.* The charge is retained by the air for some considerable time.

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* The experiments do not show which of these views is correct.

(3) The sign of the charge remaining in the air depends upon the nature of the material used. "Acidic" bodies, such as finely divided silica or molybdic acid, give to the air a negative charge, whilst "basic" bodies, such as lead oxide, or organic dusts, such as flour or coal, give a positive charge.

(4) The total electrification of dust and air is zero.

(5) The friction between particles of similar material apparently produces sufficient electrification to account for the charges observed.

(6) An unweighable amount of dust can produce an easily measurable charge.

My thanks are due to Prof. Sir J. J. Thomson for the kindly interest he has taken in this work, and also for his valuable criticism during its progress.

The Electrical Ignition of Gaseous Mixtures.

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1. *Introduction.*

The ignition of explosive gaseous mixtures for experimental purposes is generally made by an electric spark or train of sparks between fixed